Adaptive Mesh-Refinement Algorithms for Parallel Unstructured Finite-Element Codes

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At LLNL, the state-of-the-art solvers used for solid mechanics and electromagnetic simulations have sufficient architectural and functional maturity to benefit from the introduction of appropriate adaptive mesh-refinement (AMR) strategies. These new tools will enable analysts to conduct more reliable simulations at reduced cost, both in terms of analyst and computer time. Previous academic research in AMR has focused on error estimators and demonstration problems. Relatively little progress has been made on producing efficient implementations suitable for large-scale problem solving on state-of-the-art computer systems.

Research issues that we will consider include: effective error estimators for nonlinear structural mechanics and electromagnetics problems, local meshing at irregular geometric boundaries, and constructing efficient software for parallel computing environments.

Project Goals

The objective of this research is to implement AMR algorithms in unstructured finite-element codes used for solving nonlinear structural and electromagnetics problems on ASC-class, multiprocessor parallel (MPP) computers

Relevance to LLNL Mission

Many programmatic problems will be solved with greater precision and accuracy using the new AMR technology. Successful completion of this project will position LLNL as a leader in parallel finite-element technology by providing capabilities not present in other analysis systems.

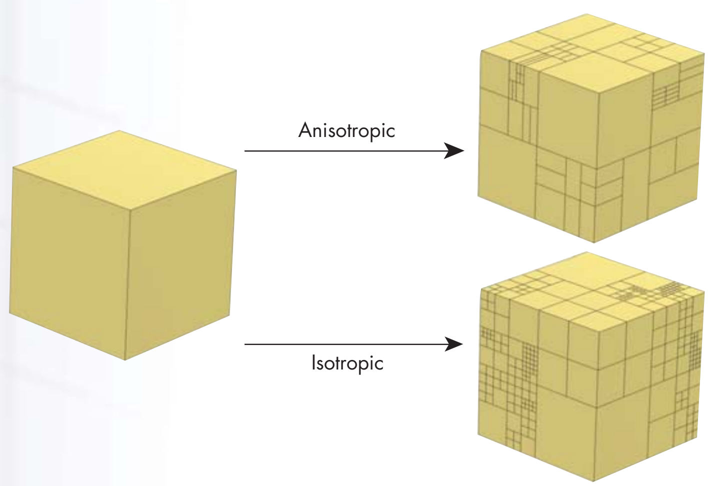

Figure 1. Meshes generated using isotropic and anisotropic *h*-refinement.

FY2004 Accomplishments and Results

To date, a serial AMR capability has been added to Diablo, a parallel structural analysis code. This includes the data structures and algorithms required to refine a user-defined mesh and error estimators based on patch recovery techniques and residual computations. Simple test problems have been constructed to confirm the correctness of the implementations.

The AMR implementation is able to perform both isotropic and anisotropic refinement as well as derefinement of a mesh (Fig. 1). Anisotropic refinement (i.e., refinement based on a directional error estimator) and derefinement are crucial for solving highly transient problems and implicit analysis, where the cost of solving equations can increase considerably with problem size.

Both residual- and patch-based error estimators are being developed for specific application to large-deformation solid mechanics problems with contact. A patch recovery scheme has already been implemented, and is undergoing testing. Two different kinds of residual-based schemes are now being implemented. Design of the parallel implementation is currently underway. Algorithm and software documentation are being produced using the UML that will form the basis of the abstraction of the AMR schemes. Coupled thermomechanics simulations have been conducted to demonstrate the capabilities of the current AMR implementation in Diablo (Fig. 2).

For electromagnetics, a global L2 projection-based error estimator has been developed and tested (Fig. 3), and a local patch recovery-based error estimator is currently under development. Both of these error estimators, at present, are limited to single material problems. Extension of these error estimators to multiple material problems will occur next year.

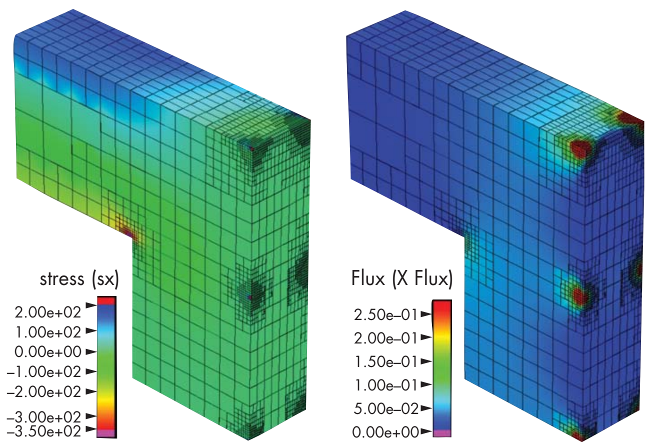

Figure 2. Stress and temperature gradient fields in a plate subjected to mechanical and thermal loads.

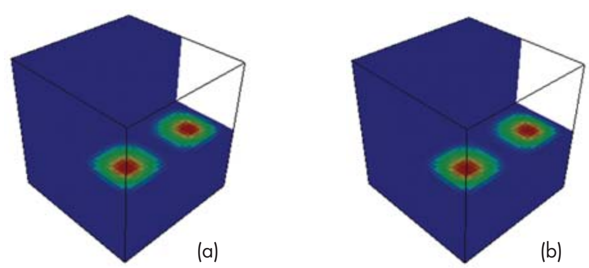

Figure 3. (a) Actual error and (b) estimated error showing the effectiveness of the error estimator for an electromagnetics demonstration problem.

FY2005 Proposed Work

The serial unstructured functionality developed for solid mechanics will be used to investigate the effectiveness of published algorithms for estimating discretization errors and for interpolating state variables to refined meshes. If necessary, improvements will be explored. The AMR functionality will be parallelized for efficient performance on MPP systems by introducing mesh-partitioning capabilities for allocating load-balanced subassemblies of a refined unstructured mesh to the available processors. The underlying data structures will be modified to account for the resulting additional interprocessor communications.

A hierarchical mesh-refinement capability will be combined with the error estimators to form an automatic AMR capability for electromagnetics. Optimization of the algorithm for parallel efficiency will also be conducted.